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ARMORED FORCE MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

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April 26, 1943

1. PROJECT: No. 3, Toxic Gases in Armored Vehicles. First Partial Reports on: Sub-project No. 3-4, Determination of Basic Ventilation Characteristics of Tanks of the M4 Series; Sub-project No. 3-6, Determination of Basic Ventilation Characteristics of Tanks of the M5 Series.

a. Authority - Letter Commanding General, Headquarters Armored Force, Fort Knox, Kentucky, 400.112/6 GNOHD, dated September 24, 1942.

b. Purpose - To determine the basic characteristics and limitations of the system of crew compartment ventilation employed at the present time in the M4 and M5 tanks as related to the protection provided to the crew members.

2. DISCUSSION:

a. The purpose of ventilation of the fighting compartment in a tank is to insure, as far as possible, a reasonably safe atmospheric environment and one in which the efficiency of the crew will not be seriously impaired. The most important functions of crew compartment ventilation are: (1) control of gun fumes; (2) removal of excess heat; (3) effective heating of crew in cold weather; (4) control of dust; (5) protection against chemical warfare agents.

b. Crew compartment ventilation in the M4 and M5 tanks is provided as a by-product of the engine ventilation and is not subject to independent control.

c. This system of negative-pressure ventilation is wholly incapable of meeting certain of the desired functions of crew compartment ventilation and meets the others only in part. A complete discussion of the characteristics and limitations of ventilation in the M4 and M5 tanks is presented in the Appendix.

3. CONCLUSIONS:

a. Control of gun fumes.

1. Gun fumes can be adequately removed by the present ventilation when the rate of effective ventilation in the zone of release of fumes is sufficiently high.

2. The distribution of air flow through the M4 tank is such that the effective ventilation rate in the turret is only 25% of the overall rate. This is not sufficient to control gun fumes except at high engine speeds.

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3. Control of fumes from the 75 mm gun has been provided by a turret exhaust fan which operates independently of the main crew compartment ventilation.

4. In the M5 tank the rate of effective ventilation is adequate for the removal of gun fumes.

b. Removal of heat.

1. When operating at cruising speed the rate of ventilation provided in the M4 and M5 tanks is sufficient to remove solar heat and the moisture given off by the crew.

2. With engine idling, the effective ventilation in the turret of the M4 tanks is not adequate for the removal of solar heat.

3. The ventilation now provided in the M4 and M5 tanks is ineffective in reducing the heat load from the transmission and final drive housings. For complete control of this source of heat effective insulation is required. The situation can be improved, however, by better distribution of air flow within the tank.

c. Crew Compartment heating.

1. A system of negative-pressure ventilation increases the difficulty of providing adequate heat for the crew in cold weather since it does not allow the heating of the incoming air.

d. Dust control.

1. Control of the dust within the tank is not possible with a system of negative-pressure ventilation.

e. Protection against chemical warfare agents.

1. Protection against chemical warfare agents released outside the tank is not possible with a system of negative-pressure ventilation.

2. Protection by negative-pressure ventilation against chemical warfare agents released within the tank is possible only if the outside air is not contaminated at the same time.

3. With the engine idling, the overall rate of ventilation and the distribution of air flow within the M4 tank are not adequate for rapid removal of agents released within the tank, particularly in the turret.

4. RECOMMENDATION:

a. That this report be distributed to interested agencies.

Submitted by:

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1 Inclosure

Appendix with
Tables 1 thru 7
and Figure 1

APPENDIX

1. Method of Ventilation in M4 and M5 Tanks

Crew compartment ventilation in the M4 and M5 tanks is obtained as a by-product of the engine ventilation and is not subject to independent control. A portion of the engine-cooling air is drawn from the crew compartment through openings in the bulkhead, the air gaining entrance to the crew compartment through ventilators in the hull and turret and through miscellaneous leakage openings such as the gun mounts, hatches, etc. The rate of air flow through the fighting compartment varies with engine speed. It is at a minimum when the engine is idling and increases several-fold when the engine is operating at cruising speed. No ventilation is provided at all (except by natural convection) when the engine is not running.

Ventilation is of the so-called negative-pressure type; that is, the pressure within the tank is below atmospheric and, as a consequence, air flows in through all openings in the structure. The quality of the air supplied is entirely dependent upon the outside air supply and any contaminant such as dust or chemical warfare agent, is immediately drawn into the tank. Since air enters through a multitude of openings, purification of the supply is not possible.

Entrance of the air through so many openings permits no control of the distribution of flow through the crew compartment and, as a result, certain zones may be relatively well ventilated while others are supplied with an insufficient amount of air.

2. Functions of crew compartment ventilation

The overall purpose of crew compartment ventilation is to insure, as far as possible, a reasonably safe atmospheric environment for the crew and one in which their efficiency will not be seriously impaired. The most important functions of the ventilating system, in this connection, are:

- (a) Control of gun fumes
- (b) Removal of excessive heat
- (c) Effective crew heating in cold weather
- (d) Control of dust
- (e) Protection against chemical warfare agents.

The characteristics and limitations of the present system of ventilation in the M4 and M5 tanks are discussed in the present report with respect to each of these functions. Preceding this discussion, data are presented relative to the overall rates of ventilation and the distribution of air flow through the fighting compartment.

3. Total Ventilation Rates

a. Procedure - Ventilation rates in the fighting compartment of the M4 and M5 tanks were determined with the tank buttoned-up and the engine operating at idling speed. All tests were conducted within a building to eliminate the variable effects of wind.

Air flow was measured by the "dilution" technic wherein a suitable test gas (toluene vapor) was introduced into the tank at a constant rate and its concentration at a given station determined at timed intervals during the feeding period and until all of the gas had been removed after feeding was stopped.

In each test the concentration built up at a definite rate to an approximate equilibrium level which was maintained until the feed of the test gas was shut off, after which it decreased at a rate equal to the rate of buildup.

From the data thus obtained, rates of ventilation were calculated as follows:

$$\text{Ventilation rate:} \quad Q = \frac{F}{C_e} \times 10^6$$

where Q = rate of ventilation (cfm)
F = rate of feed of test gas (cfm)
C_e = equilibrium concentration (parts per million)

The order to determine the overall rate of ventilation, the test gas was introduced into the inlet of a centrifugal mixing fan mounted in the bow, the purpose of which was to insure rapid and complete mixing of the test gas with the total stream of air passing through the tank. Propeller fans were mounted on the turret floor for further mixing. Gas concentrations were measured at an outlet in the bulkhead.

b. Results - Rates of overall ventilation for the four models of the M4 tank and for the two models of the M5 at normal idling engine speed are given in Table 1. Variations in ventilation rate with engine speed for the M4A3 and M5A1 (with bulkhead doors closed and open) tanks are presented in Table 2.

With respect to the M4 series, it will be observed that the ventilation rate in the M4A1 is significantly higher than in the other models. This is accounted for by two conditions: (1) owing to the greater restriction at the main air inlet, the negative pressure in the engine airwell is greater than in the other models (0.15 inches as compared with 0.09 inches in the M4A3, both at normal idling speed). This results in a larger portion of the engine air being drawn from the fighting compartment which is accompanied by an increase in negative pressure within the fighting compartment (0.14 inches at normal idling speed as compared with 0.04 inches

Table 1
 Total Ventilation Rate at Normal Idling Speed
 (M4 and M5 Tanks)

Tank and Model	Idling Speed RPM	Negative Pres. in Tank Ins. H ₂ O	Rate of Ventilation cfm	Clearance Rate*, sec.
M5	600	0.04	400	17.5
M5A1 (Blkhd Open)*	600	0.04	560	13.0
M5A1 (Blkhd Closed)*	600	0.03	440	16.5
M4A1	800	0.14	1000	10.0
M4A2	400	0.03	400	26.0
M4A3	500	0.04	520	20.0
M4A4	500	0.04	480	21.5

* The rate of ventilation remained substantially constant with the bow fan off, exhausting or inducting.

† Time required to reduce concentration of contamination within the tank 50%.
 Multiply these values by 7 to get time required to clear tank 499%.

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Table 1

Table 2
 Total Ventilation Rate in Relation to Engine Speed
 (M4A3 and M5A1 Tanks)

Engine Speed, RPM	Total Ventilation, cfm		
	M4A3	M5A1	
		Blkhd. Open	Blkhd. Closed
500	520*	440	360
600	640	560*	440*
800	860	790	600
1000	1100	1020	760
1200	1330	1300	910
1400	1580	1550	1080
1600	1820	1800	1230
1800	2080	2080	1400
2000	2320	2380	1580
2200	2560	2660	1760
2400	2830**	2960**	1910**

* Ventilation Rate at Normal Idling Speed

** Ventilation Rate at Maximum Cruising Speed

Table 2

Incl. #1

in the M4A3). (2) The total area of openings in the bulkhead is greater than in the other models (two radiators instead of one and a large opening for the passage of the drive shaft).

The total ventilation is approximately the same in all three M4 tanks powered with liquid-cooled engines. The volume of the fighting compartment is about 250 cu. ft.; thus, the ventilation provides a rate of air change for the tanks as a whole of two volumes per minute. It follows from this that the air within the tank is exchanged to the extent of 99% in 2½ minutes*. In the M4A1, on the other hand, the overall rate of air change is 4 times a minute. In the M5 tanks the rate of ventilation is also approximately 500 cfm and since the cubical space is less than that in the M4 tank (approximately 170 cfm) the rate of air change amounts to three volumes per minute. Clearance rates for the several tanks are given in Table 1.

The overall ventilation increases markedly with engine speed (Table 2). In comparison with the situation with the engine idling, when the tank is being driven the ventilation is increased as much as five hundred percent. Thus, a tank with inadequate ventilation when stationary and with the engine idling may be effectively ventilated at higher engine speeds.

4. Effective Ventilation at Crew Stations:

From the standpoint of control of gun fumes and other contamination released within the tank, the overall ventilation is not as important as the effective ventilation at the several crew positions in relation to a specific source of contamination. That is to say, for a given point of introduction of the contamination, say the breech of the 75 mm gun, the concentration which is developed at the Loader's position, for example, depends not upon the overall rate of ventilation, but rather upon the relative ventilation in the breathing zone of the loader. This, in turn, depends upon the pattern of air flow through the tank and the degree and rapidity of mixing of the contamination with the tank air. Under the most adverse conditions there might be more or less direct travel of the contamination from its source thru the breathing zone of a particular crew member without appreciable mixing and dilution in the incoming clean air. In contrast, at another position, the pattern of flow might be such as to introduce fresh air constantly with the admixture of little or no contamination. Thus, we might have the situation of entirely adequate overall ventilation but ineffective use of the ventilating air because of improper distribution of flow and insufficient mixing.

Approximate distribution of flow through the various leakage openings in the M4 tank is given in Table 3. It will be noted that the flow is divided equally between the turret and the hull. A considerable portion of the hull ventilation enters through the rear hull ventilator and passes

* Theoretically, five air changes are required to effect a 99% exchange of the air in a given space.

Table 3

Approx. Percentage Distribution of Airflow Thru
Leakage Openings of M-4 Tank

I. TURRET	PERCENT
a. Turret Hatch - - - - -	8.0
b. Turret Hatch Race - - - - -	1.5
c. 75 mm Gun Mount - - - - -	20.0
d. Turret Ventilator - - - - -	10.0
e. Three Turret Periscopes - - - - -	10.0
	49.5%
II. HULL	
a. Driver's Hatch - - - - -	3.0
b. Asst. Driver's Hatch - - - - -	3.0
c. Two Bow Periscopes - - - - -	6.5
d. Rt. Bow Ventilator - - - - -	10.0
e. Lt. Bow Ventilator - - - - -	10.0
f. Bow Mch. Gun - - - - -	4.0
g. Turret Ring (variable, depends on greasing)4-	
h. Rear Hull Ventilator* - - - - -	14.0
	50.5%

* No splash plate below ventilator, hence, less resistance

Table 3

Incl. #1

directly to the bulkhead without mixing with the general tank air. It may be considered as wasted so far as crew benefit is concerned. In the turret, nearly one-half of the flow is contributed by the gun mount at a considerable distance below the roof and, as a consequence, has very little effect upon air exchange in the upper zone of the turret. The turret roof ventilator contributes only a small fraction of the flow.

In the M5 tank, which has only one ventilator, a better distribution of flow is obtained because of the great leakage around the 37 mm gun mount and turret ring. Together, they contribute over 2/3 of the total ventilation whereas in the M4 only 20% of the flow is contributed by the corresponding openings.

The actual rates of effective ventilation at the several crew stations were determined in relation to the removal of contamination from specific sources: at the breech of the 75 mm gun, co-axial turret machine gun and bow machine gun. In each case the toluene vapor was dispersed at a low velocity (less than 10 fpm) at the breech of the gun so as not to disturb the normal air movement. Since the vapor was warmer (approximately 100°F) than the air this tended to offset the greater density of the air-toluene mixture as compared with air alone. This method of introducing the test gas does not duplicate the manner of release of actual contamination as, for example, from the firing of the gun. It was employed as a standard procedure, however, since it could be duplicated whereas the manner in which actual contamination is introduced varies widely from one test to another. The rates of effective ventilation thus determined are given in Table 4.

The values given in the table are not specific in the sense that they represent actual rates of air flow. On the contrary, they are hypothetical values which merely indicate the relative ventilation at various positions in the tank measured by the release of contamination at a given point. Consider, for example, the high effective ventilation rate in the bow for gas release in the turret of the M4A4 tank. Obviously, a rate of air flow of 4000 cfm does not exist here, but, relative to other areas, the amount of contamination reaching the bow is very small and when mixed with the fresh air introduced in the area, a low concentration of the test gas results. In the same way, the very low effective ventilation rate in the assistant driver's position in relation to the breech of the bow machine gun as a source of contamination results from the fact that the two points (source and sampling) are so close together that there is little opportunity for the test gas to mix with incoming air before it reaches the breathing zone of the gun operator. The values are therefore to be considered only in relative terms.

Two points of considerable interest are evident from the comparative rates of effective ventilation shown in the table:

- (a) The ventilation of the turret is considerably lower than the overall ventilation of the crew compartment.
- (b) The pattern of air flow is such that there is very little mixing of air (and contamination) between the turret and the bow.

Table 4
 Effective Ventilation Rates
 At Crew Positions
 (Engine Operating at Normal Idling Speed)

Tank and Model	Source of Test Gas	Effective Ventilation Rate CFM				
		Commander	Loader	Gunner	Driver	Asst. Driver
M4A2	75 MM Gun	125	87	458	--	---
M4A3	75 MM Gun	279	105	310	--	---
M4A4	75 MM Gun	105	150	324	--	---
M4A4	Turret MG	740	102	706	4150	---
M4A4	Bow M G	--	4000	--	474	56
M5	37 MM Gun	232		512	572	---

Table 4

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Thus, for a given amount of contamination released in the turret of the M4A4 at the breech of the 75 mm gun, two of the turret crew members will be exposed to concentrations approximately four times greater than they would be if the total air flow through the tank were available for immediate dilution of the contaminant. In the same way, the position of the bow machine gunner is particularly badly ventilated with respect to contamination released at the breech of this gun. On the other hand, the air flow through the turret and bow are more or less independent of each other and consequently the crew members in the one area will not be seriously affected by contamination released in the other.

So long as a system of negative ventilation is relied upon, the distribution of air flow within the tank will be determined largely by the location and relative capacity of the several air inlets. In the M4 tanks four ventilators are especially provided for the purpose of introducing air into the tank. Individually, however, they contribute less than 10% of the flow and more than 60% of the air flowing through the crew compartment still enters through miscellaneous leakage openings (such as the gun mounts, periscopes, hatch covers, etc.) and is not subject to control as to quantity or direction of flow.

In order to obtain positive control of the air distribution, three measures are suggested: (a) provide larger ventilators, that is, with greater capacity relative to the total flow; (b) install fans in the restricted ventilators to increase the air flow, and (c) relocate the ventilators and/or provide suitable adjustable deflectors for the control of direction of flow of the air.

a. Increasing ventilator capacity. The free area of the present ventilator is only 0.07 sq. ft. and the orifice area is even smaller because of the several changes in direction of flow. As a consequence, the air flow per ventilator is less than 10% of the total ventilation. The difficulties involved in increasing the capacity of the ventilator without destroying essential ballistic characteristics are appreciated. Further development is desirable, however, since the present ventilators are of such limited value.

b. Control of Air Distribution by Means of Ventilator Fans. The proportion of the total inward flow which is contributed by the ventilators can be increased through the use of accessory fans. This is now done in the M5A1 and also in the M7 tank. The benefits to be derived therefrom depend upon the location of the ventilators and more particularly upon the amount of air introduced. The use of fans of limited capacity may actually decrease the effective ventilation in certain crew positions. Thus, in the M5A1 when the bow fan was operated on intake the effective ventilation rate in the turret decreased as much as 20% below the rate when the fan was not operated. In the same way, in the M7 tank equipped with five ventilators and fans, operation of the fans on intake reduced the effective turret ventilation nearly 50% as compared with the situation when the fans were off. In both cases, the overall ventilation rate in the tank

was increased, but the distribution of flow was altered. Since there was a decrease in the negative pressure within the tank in both instances, the amount of air leaking in through the turret ring, around the gun mount, etc. was greatly reduced and, indeed, became zero in the M7 tank. Air flowing in at these points is evidently more effective in the turret than is that entering through the ventilators. The greater effectiveness of the miscellaneous leakage areas as compared with the ventilators, was further demonstrated when the fans were reversed and made to exhaust air from the tank. Under this condition the negative pressure within the tank was increased with a corresponding increase in the leakage around the gun mount, hatches, etc. In both the M5A1 and the M7 the effect was to double the effective turret ventilation as compared with that obtained without fans in operation (Table 5).

c. The importance of proper location of ventilators is evident from the foregoing. In the M4 tank one ventilator near the bulkhead is of very little value so far as crew ventilation is concerned. The two sponson ventilators are also poorly located. Moreover, they are confined to such a degree that booster fans and deflectors tubes could not be installed. Within the limits of overall tank design and arrangement of equipment ventilators should be more carefully located with reference to the crew members.

5. Characteristics and limitations of ventilation in M4 and M5 tanks in relation to the essential functions of tank ventilation.

Five essential functions of the ventilating system in a tank were listed above. Some of these are served in part by a system of negative ventilation; others, not at all. The characteristics and limitations of the ventilation in the M4 and M5 tanks, as set forth above, are now considered in relation to the several functions.

a. Control of gun fume. - The gun fume problem is largely created by the system of negative-pressure ventilation employed in the tanks. The gases contained in the gun barrel after the projectile has escaped are drawn into the crew compartment when the breech is opened. Gun fume tests have shown that with the present system of ventilation a toxic gas hazard exists in the M4 tanks (see report on Control of Gun Fumes in M4 Tanks, dated February 15, 1943). The results indicate, however, that this is due to the poor distribution of air flow within the tank rather than inadequate overall ventilation. Experiments with various devices for improving internal mixing demonstrated that the fumes could be controlled without increasing the ventilation rate. It was also demonstrated that by raising the engine speed, the rate of effective ventilation in the turret could be increased sufficiently to remove the fumes. Both methods, however, are dependent upon the operation of the tank motor. Superior control is provided by an exhaust system located in the roof of the turret which captures the fumes immediately upon release from the gun. This method of control is independent of the distribution of air flow and, in fact, works equally well with or without the tank engine operating. It has been recommended for use in all M4 tanks in combat areas.

Table 5

Effective Ventilation at Loader's Station in Relation to
Operation of Auxiliary Ventilator Fans

(Engine at Normal Idling Speed)

Tank	Source of Test Gas	Effective Ventilation Rate CFM		
		Operation of Fans		
		Off	Exhaust	Intake
M5A1†	37 mm Gun	114	163	91
M7	75 mm Gun	222	463	115
M7	75 mm Gun		310**	208*

† Bulkhead louvres closed

* Turret fan exhausting, hull fans on intake

** Turret fan exhausting, hull fans off

In contrast to the M4, gun fume tests in the M5 and M5A1 tanks showed that acceptable control of the fumes is provided by the present ventilation. This is accounted for in part by the lesser amount of carbon monoxide and other toxic and irritating gases released from the smaller gun (37 mm). But of more significance is the higher overall ventilation relative to the tank volume and the superior distribution of air flow (Table 4).

In contrast to the serious gun fume problem with negative-pressure ventilation, the problem is completely eliminated when positive pressure ventilation is employed. Tests have indicated that a positive pressure of $\frac{1}{2}$ " water gage, is sufficient to force the gases in the gun barrel to the outside.

b. Removal of heat - In a buttoned-up tank exposed to the sun the air temperature within the tank is elevated above the outside temperature. There are two sources of heat - solar radiation which is distributed over the surfaces exposed to the sun and the transmission and final drive housings which are heated to a high temperature when the tank is in operation.

The degree to which the tank air temperature is increased over the ambient temperature depends upon the overall rate of ventilation and the temperature at a given crew position is determined by the effective ventilation in the area in relation to the source of heat.

The rate of solar radiation varies throughout the day, reaching a maximum of approximately 300 Btu per sq. ft. per hour on a horizontal surface. Assuming complete absorption and equal transmission of the heat to the inside and outside, the total solar heat transmitted to the inside of the tank would amount to approximately 12000 Btu per hour, maximum. With a ventilation rate of 500 cfm, this would cause an increase in air temperature of 20°F. At 2000 cfm, the increase would be 5°F. These values are in fair agreement with field observations, as shown in Table 6.

The total heat load to which the crew members are exposed in a tank is not measured by the air temperature alone. Of equal importance are the tank wall temperatures, the moisture content of the air and the rate of air movement within the tank. Interior tank wall temperatures on a moderately clear midsummer day at Fort Knox (engine idling) reached a maximum of 122°F with an outside air temperature of 85°F. On a continuously clear day with a maximum air temperature of 98°F, the maximum tank wall temperature was 141°F. In the California desert, interior wall temperatures in a buttoned-up, deadlined tank rose to 150°F (outside air temperature 104°F) and while driving across country, ranged between 120° and 130°F with an average outside air temperature of approximately 100°F. Thus, the effect of increasing tank ventilation is to decrease the interior wall temperatures and so to reduce the radiant heat load.

The moisture content of the air within a tank is increased by the evaporation of sweat from the crew members. Assuming an average rate of evaporation of 1 liter (2.2 pounds) per hour per man at high temper-

Table 6

Turret Temperatures in Buttoned-up Tanks Exposed to Sun

(Deadlined, Engine Idling and Driving)

Place	Outside Air Temperature	Tank		Excess Turret Air Temperature	Inside Turret Wall Temperature	Remarks
		Model	Operation			
Ft. Knox	85° F	M3 Med.	Deadlined	10-18° F	113-130° F	5 hrs. exp. on mod. clear day
Ft. Knox	92°-98°	M3 Med.	Deadlined	7-27°	128-141°	5 hrs. exp. on cloudless day
Camp Young, California	104° (Max)	M3 Med.	Deadlined	25°	149° max.	cloudless day
Ft. Knox	85°	M3 Med.	Eng. Idling	2-25°	102-122°	5 hrs. exp. on mod. clear day
Egypt	88°	M3 light	Eng. Idling	32°*	---	---
Ft. Knox	85°	M3 Med.	Driving	Aver. 6°	85-97°	100 miles driv. mod. clear day
Camp Young, California	110°	M4A1	Driving	5-13°	130°	cloudless day
Egypt	87-103°	Various	Driving	Aver. 10°*	---	---

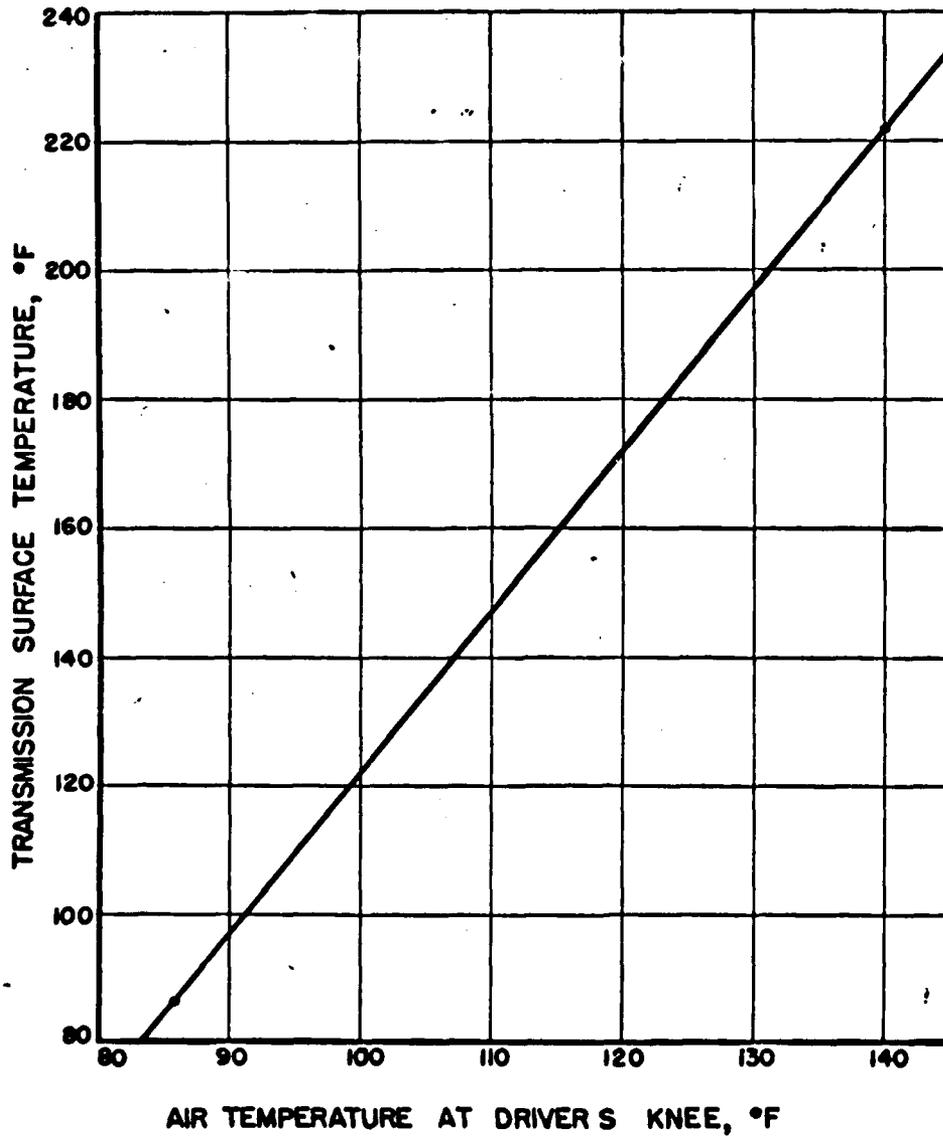
* Temperatures taken at the various crew positions.

Table 6

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FIG 1

RELATION BETWEEN UNSHIELDED AIR TEMPERATURE AT DRIVER'S KNEE
AND SURFACE TEMPERATURE OF TRANSMISSION HOUSING



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FIG 1

atures (up to 120°F), a 5-man crew will contribute 11 pounds of water per hour. In an idling tank with an overall rate of ventilation of 500 cfm., the added moisture amounts to approximately 30 grains per pound of dry air. (The foregoing calculations are in close agreement with actual observations in Egypt which showed an average increase in moisture content of 40 grains per pound of dry air.) This added moisture will increase the relative humidity of the tank air from the assumed value of 10% at 110°F to 17%, thus decreasing the potential cooling power of the air about 20%, which is not excessive.

In a moist climate, on the other hand, the situation would not be as favorable. Thus, in tropical areas like Burma, it has been calculated that a saturated atmosphere at a temperature close to 100°F may exist inside a fully-manned tank, with engine idling, and exposed to the sun. Such a condition would be intolerable.

The second source of heat-transmission and final drive housings-is localized in the bow and the heat given off markedly affects the air temperature at the driver and assistant driver's seats. The relation between the air temperature at the driver's knee (unshielded thermometer) and the temperature of the transmission housing is shown in Fig. 1. The curve was obtained from tanks deadlined, with engine idling and while driving across country. The relationship was independent of the rate of tank ventilation. Since the transmission temperature frequently reaches 250°F, it is evident that an excessive heat load is imposed upon the bow members of the crew.

The foregoing data and discussion indicate that the high rate of ventilation provided when the tank is under way (2000 cfm and over) is sufficient to insure a rapid removal of solar heat and, to some extent, the radiation from tank walls is also reduced. With the engine idling, however, the rate of ventilation is low and the distribution of air flow within the tank poor under these conditions; the turret air temperatures rise to an excessive degree. The increase in moisture content of the air also becomes of major importance in moist climates.

The highly localized heat from the transmission and final drive is not greatly affected by the present ventilation. It can be successfully controlled only by proper insulation of the hot surfaces. Very little can be accomplished by ventilation except through the cooling action of moving air. This would require, with the present system of negative ventilation, a more effective location of air intakes and means of directing an air stream toward each of the bow crew members.

c. Crew heating in cold weather - Experience in cold climates has shown that crew heating is required for efficient tank operation. The problem is not a simple one. Owing to the great mass of steel it is doubtful if a heater of sufficient capacity can be installed for general heating of the entire crew compartment. Local space heating at the several crew positions may be needed. The comfort of a man at low temperatures depends

upon the rate of air movement as well as the air temperature. It is important that the flow of cold air past the man be kept at a minimum. In this connection, the use of negative ventilation is unfortunate since it permits little or no control over the temperature of the incoming air or of the air velocity. For completely satisfactory facility for heating a system of positive ventilation is required.

d. Control of dust - With the system of negative ventilation now employed in M4 and M5 tanks, no reduction of dust concentration in tanks is possible except by means of sand shields or other devices for reducing the amount of dust on the outside. For effective dust control, a system of positive ventilation is required which permits the installation of suitable dust-removing means. In dry, cold regions, fine snow is as troublesome as is dust in arid country. For effective protection against snow, positive-pressure ventilation is also required.

e. Protection against chemical warfare agents - Tanks with negative ventilation are highly vulnerable to attack by chemical warfare agents since the toxic gases released outside the tank are immediately drawn inside. There are numerous points of entrance and there is no possibility therefore of removing the gas from the air before it enters. So far as it is possible to protect tanks from outside gas attack by ventilation, a positive pressure system with a single inlet is required. A suitable gas canister must be provided and the air flow capacity of the system will be determined by the tightness of the tank and the positive pressure required.

Protection against gases released within a tank is possible with negative as well as positive pressure ventilation, provided the outside air is not contaminated at the same time. The rate of ventilation must be sufficiently high to insure rapid removal of the contamination and thus maintain the concentration - time exposure below the safe limit.

In the M4 and M5 tanks with the engine operating at cruising speed, the ventilation rate is high enough to provide 99% clearance in 30 seconds or less. At idling speed, however, in the M4 tanks with liquid-cooled engines, the rate of ventilation is only 500 cfm and in the turret, about one-quarter of this. The clearance rate is correspondingly reduced. Under these conditions, the maximum concentration established by the release of a known amount of gas and the time which it persists within the tank are increased. Thus, in an M4A3 tank, the instantaneous release of a known amount of gas at the breech of the 75 gun resulted in a maximum concentration at the loader's position approximately 3 times the theoretical value which would be given if all the gas introduced were completely mixed with the tank air. The rate of decrease in concentration was approximately 50% in 20 seconds. Thus, if 100 gms of HCN were suddenly released at the breech of the 75 mm gun, the peak concentration at the loader's position would be approximately 42 mg./liter (42 oz. per 1000 cu. ft.) and the concentration would still be above 5 mg./liter (5 oz. per 1000 cu. ft.) at the end of a minute. It is clear that a lethal condition would be created under these conditions.

f. Negative ventilation versus positive-pressure ventilation - Reference has been made from time to time in this report to the behavior of the present system of negative ventilation as compared with the performance of a system of positive-pressure ventilation. The differences are striking, as shown by the evaluation of the two methods in Table 7. It is clear from this, that positive-pressure ventilation is the method of choice. It has the advantage of providing an independent system of ventilation designed especially for the crew and permits a degree of control in accordance with the varying requirements of the crew. It has the disadvantage of requiring additional equipment and extra power and occupies space. It is believed, however, that the benefits to be gained by positive-pressure ventilation justify the further development of the equipment. The performance characteristics of a tank so ventilated are now being investigated.

Incl. #1

Table 7
 Comparative Performance of Negative and Positive
 Ventilation in Tanks

Condition to be Controlled	Basic Ventilation Method	
	Negative	Positive
1. Gun fumes	Problem created by negative pressure. Control effective only with high overall ventilation.	Problem eliminated with positive pressure.
2. Removal of heat	High ventilation rate easily obtained but inadequate control of distribution. No possibility of conditioning incoming air.	Requires as high overall rate of ventilation as negative ventilation but better control of distribution.
3. Crew heating	Poor because no control over air distribution and no opportunity to heat incoming air.	Provides best control over distribution of flow, temperature of incoming air and rate of ventilation.
4. Dust control	Not possible with negative ventilation.	Degree of control depends only upon pressure in tank and efficiency of air clearing facility.
5. Protection against chemical warfare agents	Not possible with negative ventilation. Personal protection required.	Degree of control depends upon pressure in tank, guarding against splash and efficiency of air-conditioning facility.

Table 7

Incl. #1